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A REFINED METHOD FOR PREDICTING THE TYPE OF DESTRUCTION IN HARDENED GLASS

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A method for analytical calculation of fragmentation of hardened glass is refined based on the balance principle and the Rittinger comminution law.

The problems of predicting the type of destruction in hardened sheet glass have been repeatedly discussed in the scientific literature [1, 2]. However, no satisfactory solution for this problem in an analytical form has been found so far.

The present study is based on the known balance principle [1], when the potential energy of internal stresses in hardened glass E_p after damage is inflicted is transformed into work performed on its destruction (fragmentation) E_d:

$$E_p = E_d. \tag{1}$$

In traditional destruction of the internal stress epure in hardened glass by a quadratic parabola of the form

$$\sigma(z) = \sigma(0)\left(1 - \frac{12z^2}{d^2}\right)$$

a refined value of total potential energy “stored” by the epure was obtained in the form of the following simple expression:

$$E_p = 0.4\sigma^2(0)\,\frac{bld}{E}, \tag{2}$$

where $\sigma(0)$ is the central stress value; z is the coordinate calculated from the central plane of the glass sheet; b, l, and d are the width, length, and thickness of the glass sheet; E is Young’s elasticity modulus.

In order to calculate the second component of the balance (1), we will use the earlier described model [2] with the necessary refinements and corrections.

Let us represent the article in the form of a square sheet with a surface area $D \times D$ and thickness d (Fig. 1). Fragmentation is uniform, and the fragment size is $a \times a \times d$. Calculation is based on the first law of destruction formulated by P. Rittinger [3], according to which the work (energy) performed on fragmentation is proportional to the surface area of the newly formed surface area of the fractured object ΔA:

$$E_d = k_R\,\Delta A, \tag{3}$$

where k_R is the dimensional proportionality coefficient (Rittinger coefficient); $\Delta A = A_2 - A_1$ (A_1 is the surface area of the initial object and A_2 is the total area of emerging fragment surfaces).

Consequently,

$$A_1 = 2D^2 + 4Dd,$$

$$A_2 = (2a^2 + 4ad)n,$$

where n is the number of fragments, with $n = \dfrac{D^2}{a^2}$.

Taking into account these relationships, we have

$$\Delta A = 4Dd(\sqrt{n} - 1),$$

and the destruction energy

$$E_d = 4k_R Dd(\sqrt{n} - 1). \tag{4}$$

The biggest difficulty in using analytical expressions (3) and (4) is the indefiniteness of the main coefficient k_R. This problem for hardened glass can be solved as follows.

In the first stage we will equate the right parts of expressions (2) and (4):

$$0.4\sigma^2(0)\,\frac{bld}{E} = 4k_R Dd(\sqrt{n} - 1).$$

Since for the model accepted $b = l = D$, after brief transformations we obtain

$$k_R = 0.1\,\frac{D\sigma^2(0)}{E(\sqrt{n} - 1)}, \tag{5}$$

whence it is clear that the parameter k_R depends on the central stresses level, the elasticity modulus, the sizes of the

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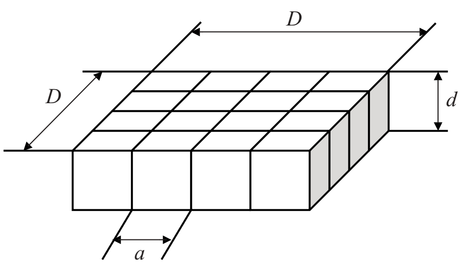

Fig. 1. Scheme of fragmentation of hardened sheet glass.

plate, and the number of fragments. Considering that $E = \text{const}$, the following technique can be used for the determination of k_R.

It is known from multiple testing data that for $\sigma(0) \cong 40$ MPa, the value n is equal to the minimum permissible number of fragment per square 5×5 cm, i.e., $n = N_{min} = 60$ (standard values in most European countries). Consequently, considering that for silicate window glass $E = 0.68 \times 10^5$ MPa, the sought-for parameter k_R can be determined, which is equal to 1.744×10^{-5} J/m^2.

Thus, the absolute value of k_R adequately characterizes the specific consumption of energy in the fragmentation of hardened silicate glass and can be used later to construct its generalized characteristic, i.e., the degree of fragmentation depending on $\sigma(0)$.

In particular, expression (5) can be solved with respect to a number of fragments obtained per standard square:

$$N = \left(\frac{0.005\sigma^2(0)}{k_R E} + 1\right)^2$$

or taking into account the found value of k_R and the constant elasticity modulus E:

$$N = (4.216 \times 10^{-3}\,\sigma^2(0) + 1)^2.$$

According to this relationship, a generalized characteristic $N = f(\sigma(0))$ has been obtained, which is shown in Fig. 2.

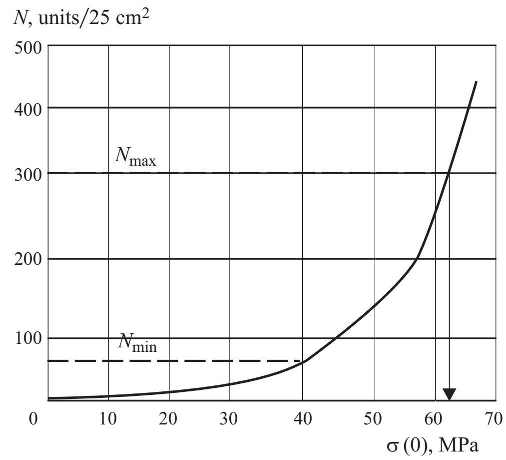

Fig. 2. Generalized characteristic of hardened glass fragmentation.

According to this characteristic, on the one hand, the refined variant corroborates the dependence of n on $\sigma(0)$ in the form of a parabola of the 4th power [1]. On the other hand, the plot shown makes it possible to identify acceptable internal stress zones, which correlates with the minimum permissible number of fragments for $\sigma(0) = 40 - 60$ MPa and the maximum permissible number for $\sigma(0) = 62 - 300$ MPa.

Thus, the analytical study performed has identified the acceptable technological range of the level of hardening for sheet glass, which can be effectively used in the theory and practice of thermal treatment.

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